HOW CAN ATOMS, THE FUNDAMENTAL OF CHEMISTRY, BE TAUGHT ADEQUATELY IN THE 21st CENTURY?

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Abstract

This paper is a systematic contribution to Pedagogical Content Knowledge (Shulman, 2004) on teaching atoms in Chemistry. We justify our normative starting points (we call them "axioms") and proceed

- *from axiom #1 – science education's foremost goal is comprehension,*
- *to axiom #2 –comprehension can exclusively be achieved by an individual, be it the teacher or the learner,*
- *then further to axiom #3 and #4 – on the part of the teacher, both her understanding of the subject matter (content) and of learning (its process and perspective) can be expected to lend considerable importance to the way she designs and organizes teaching & learning situations in school science (axiom #3), – on part auf the learner teachers must presuppose a will to learn (axiom #4)),*
- *and finally come to axiom #5: Any teaching any design of teaching & learning situations in school science must take concordant to contemporary science.*

In this justification process we discovered that the different understandings of comprehension found empirically by Helmstad (1999) correspond neatly to the different didactical approaches of teaching atoms, i.e. the particulate nature of matter. These findings enable both teachers and curriculum designers to make theoretically better founded choices.

Key words: *pedagogical content knowledge, PCK, approaches to teaching atoms, teaching atoms, understandings of understanding, understanding atoms.*

Introduction – Pedagogical Content Knowledge (PCK)

Worldwide Teacher Training has, for a very long time, consisted (and in some places still does consist) of two main parts: of Content Knowledge and of Pedagogy. Content Knowledge covers the basics of the particular science that the coming teacher is supposed to teach in her specialisation, say Physics or English Literature or Mathematics. Pedagogical Knowledge on the other hand, is usually an introduction to the basics of school pedagogy, say Instruction or Psychology of Learning. – The knowledge of *what is* actually *being learned by the learner* (and this is by far not identical with what is supposed to be learned!), however, has so far gained little systematic attention in Teacher Training, although, since twenty or thirty years *research* on *topical* learning processes, say, how Newton's Axioms are understood or misunderstood in the course of science education in school (see for instance Bowden, & al. 1992) has come to blooming. This type of knowledge obtained in science education research was termed *PCK* – Pedagogical Content Knowledge – by Lee Shulman in his famous presidential address to the American Educational Research Association in 1985 (Shulman, 2004, 187ff), and the term has been gaining more and more acceptance in recent years (see for instance, van Driel, de Jong & Verloop 2002, Hasweh 2005, Eilks & Ralle, 2006; Berry, Loughran & van Driel, 2008; Nyberg, 2009). This does not mean, that the field of PCK, the field in between teaching and learning, in between pedagogy and science content, hat not been treated before – famous books like Martin Wagenschein's "Pädagogische Dimension der Physik" (1962) or John Bradley's "Essay on the teaching of chemistry to young people" (1988), in which he exploits the metaphor, that chemistry students "ask for bread" while they "get stones to eat", would give us the lie – it only means, that there was little systematic and institutional awareness for these aspects of learning in those times.

In the last thirty years, however, considerable research has been done on students' conceptions of various science topics. Usually such studies deal with learning difficulties, say, why students for instance stick to an Aristotelian approach while physics requires a modern, Newtonian approach (e.g. again Bowden, et al, 1992). Researchers who investigate such a question draw their abilities to discern between, say Newtonian an Aristotelian approaches (i.e. to recognize when student A argues in the line of Newton while student B argues on the line of Aristotle) from fundamental theories in Philosophy of Science like Thomas S. Kuhn's "Structure of Scientific Revolutions" (1962). In almost all studies of this type it is taken for granted, that the teacher, since she has studied her discipline at one or the other university, takes the modern, say the Newtonian, point of view in her lessons, and does want to teach only this point of view to her class. When designing didactical strategies, i.e. teaching & learning situations in school science, it is a legitimate *axiom* that what is to be taught & learned has to be completely concordant with modern science, say, with classical mechanics, when this is on the curriculum's agenda, or quantum mechanics when that is on the agenda, but never with Aristotelian or mediaeval physics.

Now, in the field of atoms in chemistry lessons this axiom is obviously not kept in conformity among the factual approaches to teaching & learning the particulate nature of matter. De Vos & Verdonk (1996) in a thoroughly thought over investigation on the content to be taught, when atoms are to be introduced in the chemistry classroom, came to a most devastating conclusion:

> „Reviewing these data, we conclude that our description of the particulate nature of matter in science education refers not to modern theories of matter. Instead it refers to a classical, micromechanical material world, governed by Newton and Coulomb, in which mass and electric charge are quantized, whereas space, time and energy are not. This description has obviously been inspired by quantitative versions of 19th century scientific theories. There is also an echo of 19th century optimism about the ability of science to produce absolutely correct explanations of all physical and chemical phenomena in (micro) mechanic terms. Later developments that lead to a rejection of classical mechanics as a source of first principles and the introduction of uncertainty and relativity as scientific concepts usually receive little attention in elementary science education." (de Vos & Verdonk, 1996, 661–662)

Their verdict leads us to the question we want to tackle in this contribution: How then can Atoms be taught *adequately* so that it fits to the generally not disputed axiom which maintains that, what is to be taught & learned, has to be concordant with modern science?

Methodology – How We Will Reason in the Contribution

Research on PCK usually proceeds by declaring why the content to be taught and/or learned is important, or –at least – that it is legitimized by curricula or prescribed national standards. Bindernagel & Eilks (2008), for instance, who studied experienced chemistry teachers' PCK of *models* and *the process of modelling* begin their paper with a statement on modelling as an important process in the realization of knowledge, which in addition serves as a medium of communication, mentioning also that their topic is listed among the German National Competence Standards for Secondary Schools of 2004 (KMK 2004). – We, in contrast, do not proceed from the content-side of PCK but from its pedagogy-side. We reckon: First of all it are persons who go to school. What and to what purpose they learn is for the sake of their personal thriving, for their individual development. So our foremost axiom (theorem) for science education can be put like this: *Science Education's foremost goal is comprehension*.

As comprehension can exclusively be achieved by an individual person (teacher and learner are equal in this point) any research on PCK has to allow for individual *variation* (2nd axiom, cf. Marton & Boooth, 1997). – On the part of the teacher her or his understanding of *both* the subject matter (content) *and* of learning (its process and perspective) can be expected to lend considerable importance to the way she designs and organizes teaching & learning situations in school science (3rd axiom). On part of the learner achievement of comprehension presupposes (at least) a will to learn (4th axiom). And only as a 5th axiom quality standards come within horizon: We maintain that now, after a hundred years of research on the physics of atoms, the results of modern [quantum] theory cannot anymore be held outside school science education.

By proceeding thus we are obviously in line with the continental European tradition of *Bildung* and rather not in line with the Anglo-Saxon concept of *scientific literacy* (Frost, 2006, Rehm, 2008, 319-324). The metaphor 'literacy' alludes that doing science is a kind of skill, is something like reading, writing or doing arithmetic, whereas 'Bildung' rather means personal competence, identity shaping[1] .

To open the next paragraph we will argue why Phenomenology (as a philosophy of science, cf. Husserl 1970[2]) is more suitable to lend support to our axioms mentioned above than Constructivism. This will lead us to the special concept of PCK-investigation called Phenomenology (cf. Marton & Booth, 1997). We will take the results of such a phenomenological study on the notion of understanding ("comprehension") by Helmstad (1999) and compare his outcome with existing didactical strategies, i.e. teaching & learning approaches to introducing atoms in the chemistry class. If we find any correspondence between them we are up to *explain* the existing concepts by different understandings of what kind of understanding might be expected (cf. axiom 3). We will finally suggest, that those who understand their own driving forces will make better didactical decisions. By arguing in this direction we take up Sandra Abell's criticism, who, looking back on twenty years of PCK and asking "Does PCK remain a useful idea?" (Abell, 2008), remarks:

> "To date, science teacher PCK research is mainly descriptive. We need strong descriptions of science teacher PCK, but we also need to think about how our research can help solve the dilemmas of science teacher learning. Ours is an applied research field, and we must consider the usefulness of PCK research to answer the big questions in science teacher education: Why do teachers who go through science teacher preparation Programmes aimed at reform-minded instruction still teach the way they were taught? Why is it that teachers do not always learn from experience? Why is it so hard to change the landscape of science teaching and learning? PCK research must explain something about these bigger questions in order to be useful." (Abell 2008, 1413)

We fully agree with Abell, and we think our contribution offers such an explanation – the explanation why some teachers prefer this didactical strategy of introducing atoms and some teachers that one. And we might also explain how de Vos & Verdonk's heavily criticized findings come about.

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[1] Much of this difference between the Continental European and Anglo-Saxon tradition is also discussed in Hopmann's books on „Didaktik"vs. "Curriculum" (Hopmann, 1995; Westbury, Hopmann & Riquarts, 1999; Gundem & Hopmann, 2002).

[2] Please note that throughout this paper we use the term 'phenomenology' or 'phenomenological' only in this connotation with Phenomenology as a Philosophy and *not* to denote any physical appearance

Coming to Results: the Coherence of Helmstad's Research Findings on "Understandings of Understanding" with Common Teaching Strategies to Introduce the Particulate Nature of Matter

Re Axioms 1 and 2: The term 'understanding'; its phenomenological base; the reasons why we rely on phenomenological research, although both constructivism and Phenomenology comply with axiom #2

Our 2nd axiom draws on the quite undisputable experience that comprehension can only be performed by the comprehender, the learner or the teacher or just any person who understands. – We just used two verbs – *to comprehend* and *to understand* – which by themselves are slightly different in meaning but were used here as synonyms. It is helpful to clear the linguistic situation in advance by giving a more or less elaborate list of homonymous meanings of the word *to understand*. In this case we are lucky, that *to understand* – English, this paper's language –, *verstehen* – German, the authors' language –, and *föstå* –Swedish, the researcher Helmstad's language, upon whose study's on understanding we will call later – appear to be quite similar words as far as their linguistics are concerned. And above all we can use Immanuel Kant's clarification of these homonyms as he distinguishes them clearly by using specific Latin words to characterize every different homonymous meaning of *to understand,* of *verstehen* and of *föstå*: (1) percipere; (2) noscere; (3) cognoscere; (4) intellegere; (5) perspicere; (6) comprehendere – all being different forms of *understanding*.

It is clear why we use the word *comprehension* when we mean the highest level of understanding, whereas we use *to understand* when we mean either one or all of the six particular meanings Kant (1820, 71-72) mentioned.

Now, *understanding* shares its undisputable feature of inseparability from the person who understands with *experience* and *cognition*: Nobody can relieve me from understanding, comprehending, experiencing, recognizing… And therefore it seems natural to us to take Husserl's Phenomenology as philosophical foundation for our enterprise. David Woodruff Smith (2007) just like David Zahavi (2003), both outstanding Husserl-specialists define Phenomenology as "the study of consciousness as experienced from the first person point of view" (Smith, 2007, 188, Zahavi, 2003a, chapter 2). In the process of understanding, or, to put the emphasis more ambitious: of comprehending this world, the understanding person turns to something, devotes herself to something that is not located in her mind, and thus establishes a *real* counterpart.

In Husserls theory, comprehension just like experience or consciousness is brought about as a *relationship* between the subject of consciousness (– **I** –) and the world (in Science: **Nature),** i.e. the object of the understanding person's awareness, in our case the particulate nature of matter. We might picture this *relationship* as in fig. 1.

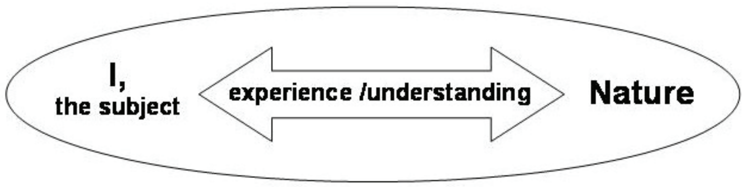

Figure 1. Experience and understanding in science education brought about as a relationship between the experiencing understanding Person and Nature.

The 'I' puts a questions, and nature 'answers' only to the questions which I, the subject, has asked. Nature does not answer in *general* and sometimes nature answers against one's expectations. In the case of atoms, quantum mechanics, relativity, she offers quite unexpected "answers". Thus, *relationships* established by the learner by building up a very personal relationships between the questioning subject and the answering nature make up the individual's singular way of understanding. i.e. the way in which she or he experiences and understands the world. Such building of personal relationships, we claim, makes up the purpose of Science Education (axiom #1).

The phenomenologists' paradigm appears more solid to us than the common constructivists' paradigm which prevails in science education. For the constructivists, the mental constructs (which are built, rearranged or may be discarded) may well be a reaction to life-world, but are, as such, to be located merely in the mind of the learners, and detached from life-world. To avoid complete solipsism *social constructivists* argue that it is language which transports understanding in the classroom via vocabulary that a social community has agreed upon in order to label certain mental constructs. Maybe it is the technical metaphor ('construction') that invites science educators to hold this widespread position. We, however, do not subscribe to it. But we must emphasize that both Constructivism and Phenomenology allow for individual *variation* (2nd axiom). Both views have in mind, that learning and understanding is an individually personal matter. When it comes to what *understanding* actually means to this teacher or that learner, we will draw upon Helmstad' research, that was performed and evaluated in a phenomenological paradigm. Both, Helmstad's research questions and his findings spring from his phenomenological approach; they would not actually lie within a constructivistic scope. It is for this reason, that we introduce the phenomenological paradigm in our paper.

Re: Axioms 3 and 4 – Different understandings of understanding

Now, detail questions arise when we consider both axioms #3 and #4, which are derivatives of axiom #2. We are to expect that both on the part of the teacher and of the learner teaching &learning will depend on different ways of what is understood by the process of understanding. Glen Helmstad (1999) has done phenomenographic research[3] into this question. He asked about a hundred persons between 12 and 75 years to call down to their remembrance a significant situation "when I understood" and write down their account. Participants were allowed to describe more than one instance. A representative group of 34 participants were then interviewed to the purpose of following up the written account, inviting the participants to give some typical examples of what "understanding" means and imagining a formulation, they would use if they were to explain it to someone else. Such interviews lasted between 25 and 120 minutes.

In two interpretative turns, each guided by a set of guiding principles, the copious personal accounts of what the selected participants regarded as typical when "understanding" takes place were systematized. This evaluation finally amounted to a set of three different ways of understanding the phenomenon '*understanding'*:

"Understanding emerged as:
1. a *reception* of new knowledge either through observation or information,
2. an *acquisition* of desired knowledge through relatively successful completion of deliberate learning activity,
3. *realization* of a new truth on the basis of experience and interpretation of experience. " (Helmstad 1999, Abstract on the book's half title)

Since *Realization Understanding* is what is meant when we speak of *comprehension* (axiom #1) we like to extend the subsystems of *Realization Understanding* as developed in Helmstad's study:

[3] Phenomenography is a well designed research method, i.e a qualitative research methodology, within the interpretivist paradigm, that investigates the different ways in which people experience something or think about something. (cf. Marton & Booth, 1997)

"3. Understanding as a realization of:
A. *factual* understanding of
1.that something is the case
2.what really is the case
B. *referential* understanding of
1.the existing meaning
2.how something appears
3.what an expression means
C. *systemic* understanding of
1.how something works
2.inherent regularity or structure
3.what something is". (Helmstad, 1999, 163)

It is this kind of factual, referential or systemic comprehension, on which we base axiom #1.

Re: Axiom 5 – What quality standards can be found in the didactical strategies that are realized in teaching the particulate nature of matter (i.e. atoms)?

Handbooks for teaching strategies in chemistry usually recommend only one particular approach of introducing "Particles", "the Particulate Nature of Matter", "Atoms" or "Atoms and Elementary Particles". There are not very many types of approach, however. Erwin Graf (2001), an experienced chemistry teacher trainer, has good arguments to discern two, more or less controversial approaches in introducing models for the particulate nature of matter, which he calls "*the informative introduction of models"* and *"the joint development of models":*

"There are two polar positions on how to introduce models in the chemistry class, which, on first glance, exclude each other. According to the advocates of position one, pupils and teacher together should develop models out of a given context, while representatives of the other position aspire to a*n informative introduction of models.* Here working with [given] models is in the fore. Supposed advantage of the first position is that the learners not just look at models and either draw information from them or attribute information to them, but are actively involved in the process of modeling [*joint development of models*] and can thus practice the method of modeling. Representatives of the *informative introduction* see the decisive advantage of their teaching approach in reducing the abundance of content to be learned, by offering only optimal models and thus making economic and easily remembered chemical education possible." (Graf, 2001, 5; our translation)

Looking closer in either one of these approaches reveals considerable shortcomings and drawbacks of them.

In a questionnaire investigation how chemistry teachers in the Southern German State of Baden-Württemberg introduced atoms Hört & Buck (2003) found out that about 88% would teach according to the *Informative Approach*. Case studies by Fischler (1996) showed that typically teachers in interview situations do well know about the provisional and hypothetic character of models, but when they speak about teaching and learning particles and atoms they speak as if it were factual items of everyday reality. Bindernagel & Eilks (2008) came to very similar results: models were mostly used simply as explanation tools without reference to their hypothetic status. And when reading the whole special issue journal edited by Graf (2001) not once the idea is brought up for discussion among the students that "explaining" the particulate nature of matter by models might not just be as factual and real as all the blackboard applications and model objects look like. Mikelskis-Seifert (2002) has analyzed German science school books and points to the problem that the wide spread inadequate dealing with the unexpected and uncommon features of atoms and elementary particles ultimately leads to a solidification if not a cementation of naïve-realistic views on particles. Higher up we have quoted the verdict by de Vos & Verdonk (1996).

The situation among the advocates of the *Joint Development of Models Approach* is somewhat different. The research group of Rosalind Driver was one of the first who proposed that the learners themselves should develop rather their own models in situations that were similar to those situations in the 19th century, when Boltzmann developed Statistical Thermodynamics (see Driver, 1992). So the Gas Laws became the content; pupils tried for instance to explain the experimentally found relationship between temperature and pressure. Other approaches exploiting the features of gases followed. Significant teaching strategies founded on constructivism were influenced by Driver's pioneer work (Nussbaum & Novick, 1981; Meheut & Chomat, 1990; Vollebregt, 1998).

Now, design of a teaching approach is one thing, but implementation and realization of this approach is another one. We take Johnston's "Constructivist Approach to Teaching the Particulate Theory of Matter" (1990) both as an enlightening example for the implementation of such an approach and for criticism from "within" – within the constructivist paradigm. On the other side we quote Matthews' criticism (1994) from outside, which was well considered among the constructivists (cf. Leach, 1998).

Johnston (1990) adapted a didactical strategy (teaching scheme) designed by Driver & Oldham (1986) to be used in 13 classrooms (13–14 year olds). Her tasks concerned diffusion as well as compressibility and density features of gases as compared to liquids and solids. The classes were held by specially instructed teachers. Johnston summarizes:

> "In almost every class participating at the trials of the scheme (and for students of all abilities) *some* students attempted to explain *some* of the tasks using ideas about atoms/particles. However, individual students showed little consistency in the ways in which they used such ideas, many using particulate ideas to explain one phenomenon but other ideas for other phenomena. Very few students freely volunteered the origins of such particulate ideas, but when questioned about them some mentioned earlier teaching (often at elementary school), television programmes and books. …There was a tendency for students to draw on everyday rather than school science experiences in constructing their explanations." (Johnston, 1990b, 250)

The teaching scheme provided for a poster presentation by the student groups in which the individual explanations – particulate or non-particulate – were discussed. The teacher then identified the gaps between the school science view and students' ideas brought forward during the poster sessions. Finally the teachers presented the school science view. They were free to handle this the way they thought to be appropriate and did it in mainly two different ways. One group of teachers made sure that the students were comfortable with the scientific ideas being put forward. The other group adopted a rather straightforward (i. e. "directive") approach without relating to the students' ideas. The teachers of the latter group were asked, why they had decided to take this approach and gave time constraints, need for closure and a lack of confidence about working from children's ideas as reasons for their decisions.

Johnstone summarizes. "For some teachers it was simply much easier to introduce the school science view than to generate a number of teaching strategies to address the wide range of ideas present in their classrooms" (Johnston, 1990b, 261). We interpret Johnstone's phrase in terms of Graf's *Informative Approach*: Some teachers were simply convinced that an informative approach would be more efficient. We will go deeper into this interpretation in our next paragraph. This interpretation basically coincides with Matthews' criticism as it was understood by the constructivists[4] . According to Matthews (1994), the teaching advocated by Driver from her constructivist perspective involved teachers who in spite of trying to keep faith with students' reasoning only lead them to desired learning goals and thus enticed them into "direct transmission of knowledge" (Leach, 1998, 8). Isn't "transmission of knowledge" just another expression for "informative approach"?

[4] We should like to emphasize, that Mathews' reproach aimed at the philosophy of science practiced by Driver' and Johnstone's teaching approach. He claims that it is,"at best, a warmed up of old-style empiricism" (Mathews 1992, 5), referring to the idea that sensory input actually makes up the "raw material" for knowledge. (cf. Leach 1998, 8)

Understandings of understanding as a concealed impact factor for designing and practising teaching

In terms of Helmstad's findings we may regard the *Joint Development of Models Approach* applied by Driver, Johnston or the other authors mentioned just as "an *acquisition* of desired knowledge through relatively successful completion of deliberate learning activity" (Helmstad, 1999, Abstract on the book's half title). For both, the designers of the teaching approach and the group of teachers who compared and discussed the spectrum of explanations – the students' explanations as well as the school science ones – and who made sure that their students "were comfortable with the scientific ideas being put forward", obviously it makes sense to elaborate understanding. To them understanding is an active process, not something that can be "transmitted". To understand in their sense requires personal commitment, presupposes to be involved in the production of explanations.

It is straightaway clear that Graf's *Informative Approach* presupposes what Helmstad (1999) calls *reception understanding.* Interesting enough, among Johnstone's teachers there were also some who regarded the school science view on diffusion, compressibility and density features as the *actual* knowledge to be taught through information. Why waste time on students' ideas which have little significance faced with the valid school science explanations, which are the true or at least the only proper targets of learning science? Given this view on the very nature of understanding to be reached in school, the poster sessions performed by their students had a different meaning: they were means and activities to ensure receptive minds in their students' heads.

So both groups of teachers, those with lasting reception-understanding as well as those with lasting acquisition-understanding, were successful and professional teachers to their own standards. Where it is not specified what kind of understanding is to be brought about in the classroom *any* understanding might be advocated, parrot understanding as well as retriever understanding as well as elaborated and reflected understanding.

But how about Helmstad's 3rd understanding of understanding – *realization* -understanding, the emergence of evidence, i.e. "a *new* truth on the basis of experience and interpretation of experience" (Helmstad 1999)? Obviously, though probably well intended, Johnstone's classes had had too little experience with explaining phenomena of their own. It took the Science Community over a hundred years of hot debates to unambiguously recognizing atoms as constitutive particle that build up matter, so one actually cannot expect 13-year-olds to find own evidence for this most important scientific theorem that all matter should be made up of atoms – unless there were an easily accessible "bridge from the macro to the micro world" (Rehm, 2007).

Jumping to the Atoms – the Nesting Systems Approach

Curiously enough, what Buck (1987, 1990) and Rehm (2007) proposed as an approach to introduce the idea of atoms is both jumping across a canyon and leisurely walking over a bridge. What we realized much later was that our very approach did presuppose a notion of understanding in terms of Helmstad's *realization-understanding*. In this article we can only skip through this third way of teaching atoms, which we could call the *Nesting Systems Approach.* We will just give a rough sketch of our approach and then justify why it fits well as an example in which *realization understanding* works as a design factor.

Take any material thing you can bring into the classroom, a bicycle, or what we call a "coke-battery" (i.e. a zinc and a copper plate, a paper napkin, some coca cola a battery, two metal wires and an electric rotor), take an egg or whatever object that can be made interesting to the class for a moment and start a discussion about the *dialectics* of the whole thing and its parts. "Dialectics" means – according to the Oxford Advanced Learners' Dictionary (Hornby 1989, 331) "the art of discovering and testing truths by discussion and logical argument". It is an old philosophical question: the relationship between the whole and its parts, and secondary students

PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Volume 17, 2009

have plenty experience necessary to "discover and test truths" on the whole and its parts, i.e. the material universe and its parts, be it bicycles, batteries or eggs, be it human bodies with their heads trunks and limbs. It is helpful to introduce the notion of *systems* and their *components*, and these semantic tools empower the students to push the class debate to both ends of the material world – to the universe as a whole with it's nebulae and solar systems as components as well as to the submicroscopic atoms, elementary particles and quarks, that can be found in popular science books, school books and internet. What happens in the class is *realization* – that the material world is a nesting system (cf. figure 2).

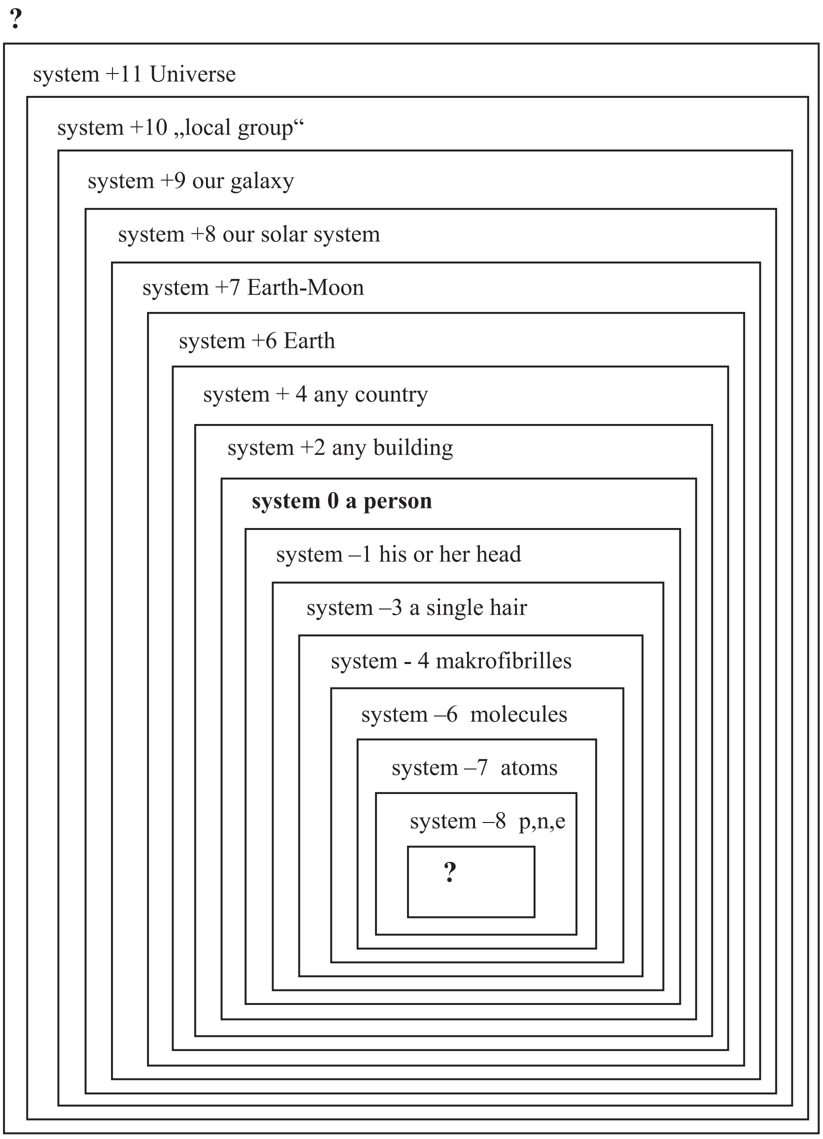

Figure 2. Scheme of the material world seen as a nesting system.

This insight is not offered explicitly by a teacher as a doctrine; it is *found* by students through individual deliberation. And the process of realization is based both on personal experience and on hereditary experience captured in books or other storage media.

The rules of this nesting system are:

- A system has new (different, additional) properties, features, if compared with its components.
- A component can have properties and features that a system might not have.
- A system might consist – on one hand – of components, but
- a system might – on the other hand – be a component of a larger system.
- Living systems are different from technical systems in quality (e.g. they can reproduce themselves or grow by autonomous intake) but not in principle.

Most important: We get an organizing principle at hand that is both elaborated on a personal level and socially validated through discussion in the class. The quality of understanding is not only different in the sense of Helmstad's classification but also different in so far that we understand now by locating the phenomenon under discussion within the nesting-system-scheme instead of by explaining, say, via models. Take a chemical phenomenon, for instance melting sulphur. The impressive change of colours on heating makes clear: colour is obviously not a property of atoms, as the atoms being the components of the portion of sulphur do not alter. Or: we find (by looking up data books) that the mass of 1 mole of carbon is *not* the sum of the masses of their atomic components, i.e. 6 moles of protons, 6 moles of neutrons and 6 moles of electrons. Well, very simple – in this micro realm the Einstein Law ($\Delta E = \Delta m \cdot c^2$) is the rule and not a law commonly called "the law of mass conservation".

And now, some features of chemistry regarded as very difficult in teaching chemistry become quite obvious:

- Atoms are components as well as systems.
- The properties and features of atoms should be different from the objects we can touch with our hands.
- The world of atoms is quite different from the world we are familiar with.
- When we talk about atoms, we talk about mental constructions deduced from many observations and not about objects like tables and chairs, which we can visually perceive.

This list of conclusions at the end of teaching by the nesting systems approach matches, to our conviction, with axiom #5: What is to be taught & learned has to be completely concordant with modern science.

Discussion

Given that *understanding* is the principal target of science education (axiom #1), instructional design for this purpose still might be quite different as it turns out that one teacher's understanding of what the process 'to understand' actually means might be quite different from his or her colleague's understanding. When she or he wants her or his students to learn something about the particulate nature of matter, i.e. the basics of atoms, and at the same time her or his understanding has the quality of *reception understanding*, then she or he will prepare a selection of interesting model explanations developed in the course of history and present the case to her class, i. e. she will practise 'transmission teaching', i. e. practise the *informative approach.* This seems to be the case in many cases as confirmed by Johnston (1990), by Fischler (1996), by Hört & Buck (2003), by Bindernagel & Eilks (2008) and others.

If and when, however, the teacher's understanding of understanding is of the *acquisition* type she or he will arrange classroom activities that enable the students to find their own explanations individually. She or he might even arrange for meta-teaching, i.e. she or he will give time for methodological discussions. Elaborated teaching approaches of this type can be found in Mikelskis-Seifert's (2003) or Vollebregt's (1998) books. Such teachers would emphasize the *process* of constructing models, and if they want to comply with curriculum prescriptions expecting that the classical atom models by Boltzmann, Bohr or Rutherford be learned they will take care that these "xenogenetic" explanations will be discussed against the background of the explanations developed in the class.

If and when, thirdly, the teacher's understanding of understanding is of the *realization* type she or he will arrange classroom activities in which "genuine understanding" (as Buck, Linder & Marton (2001) put it) is likely to be achieved. She or he will make sure, that her or his students will have enough experience of their own so that they – together with new evidence from observations as well as from statements in books – come to *realize* that atoms and submicrosopic particles *cannot* be on the same level as daily used objects, *cannot* be "touched" or "seen" like nails or marbles. Our own teaching approach (cf. Buck, Rehm & Seilnacht, 2004) heavily draws on the teaching concept "Verstehen Lehren" by Wagenschein (1968), but there are related approaches like Donald Schön's "Reflective Practitioner" (1987), Marton & Booth's "Pedagogy of Awareness" (1997, chapter 8), or de Miranda's "Niveauverhogend Scheikunde-onderwijs" (1981) in which "leading to insight" is an explicit objective.

Conclusion

As PCK is not only an endeavour to know more about preconceptions and misconceptions that hinder students to learn what they are supposed to learn but also an endeavour to understand the preconceptions of what their teachers lead to choose this or that teaching design, here in our contribution, we tried to point out, that understandings of what 'to understand' actually means will have influence on the teaching approach. We tried to establish a coherence between Helmstad's three empirically found types of understanding of understanding and three teaching approaches leading to the particulate nature of matter, i.e. to introduce atoms. These teaching approaches were identified by scanning German Chemie-Didaktik Textbooks and special issues on teaching models or atoms like Graf's (2001) or Parchmann & Rehm's (2009). If we were asked by Sandra Abell as quoted higher above: "Why do teachers who go through science teacher preparation Programmes aimed at reform-minded instruction still teach the way they were taught?" (Abell, 2008, 1413); a finding reported for instance by Johnstone (1990) or by Hört & Buck (2003) or by Bindernagel & Eilks (2008), we would answer: "Well, these teachers might have gained knowledge on reform-minded instruction, but their *understanding* (of understanding for instance) is the decisive factor; knowledge is not sufficient". We then would like to continue: "So, teacher preparation programmes aimed at reform-minded instruction should plunge deeper, should discuss the teacher trainees' *understandings* of learning, of knowledge, of understanding, and make clear that these understandings are (also) driving forces for designing a teaching approach".

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